

LOCUST WRATH: AN iOS AUDIENCE PARTICIPATORY AUDITORY DISPLAY

PerMagnus Lindborg

School of Art Design Media
Nanyang Technological University
Singapore
permagnus@ntu.edu.sg

David Liu Yuning

School of Electrical and Electronic Engineering
Nanyang Technological University
Singapore
lyn444@gmail.com

ABSTRACT

Mobile devices have been used in soundscape installations and performances over the past decade or longer, often to emphasize social interaction. Multichannel sonification has been found to successfully represent data describing kinematic phenomena. However, there are few if any examples where these two approaches are combined. The Locust Wrath project has evolved in stages: first, as surround sonifications of climate data for a multimedia dance performance; then, as a frontal display sound installation and as material in a live performance of ‘musical’ interactive sonification; and recently, as an audience participator work. We developed a system for spatialized sonification of data using a server-client model with iOS devices. In two multimedia performances, the audience members’ iPhones were employed *ad hoc* to constitute a large auditory display. This paper describes the artistic background to the project, outlines the stages, and focuses on the design and implementation of the Locust Wrath client app.

1. INTRODUCTION

This paper will first review some works that have inspired the Locust Wrath project. They are of two kinds: soundscape installations using mobile devices, and multichannel sonification displays. We then outline the concept and relate the artistic outcomes so far. The bulk of the paper is dedicated to describing the system design of Locust Wrath #3, where iOS devices are employed to constitute a large auditory display for audience participatory, spatialized sonification of climate data. Finally, limitations of the present system and some avenues for further work are discussed.

1.1. Soundscape installation with devices

An early example of ‘locative music’ was “Net_Dérive” [31]. Three iPhones were carried by performers ‘drifting’ around a Parisian neighborhood, and collecting audio and video that were automatically uploaded to the Internet. The material was recuperated at a gallery and recombined in various ways, constituting a real-time composition through which a ‘collective narrative’ emerged. The authors wanted people to be “not just passive viewers, but... able to interact with the mobile participants” through bidirectional exchange of material [32]. As a work of cultural critique, the piece aimed

simultaneously to provide tools for urban archaeology and highlight the capacity of surveillance technologies. In a similar spirit, the experience of “SoundscapesLandscapes” [22] was one of a mixed-reality soundwalk through place and time. City *flâneurs* could delve into a colorful part of Athens by visiting map hotspots where geotagged audiovisual material became accessible with a smartphone application. By gradually revealing carefully crafted interviews, soundscapes, and audiovisual compositions, the history of the neighborhood was unearthed. In “Cloud Bridge” [35], visitors at a public library could interact with a generative system with their iOS devices. Browsing and making selections contributed to parameterizing the synthesis of visuals that were displayed on screens, and of surround sound diffused over loudspeakers. Thus, the situation was akin to interactive cinema [2].

A similar, quite playful setting was found in [23]. Audience members listened to music and continuously rated their perceived emotion using handheld devices. Their ratings were graphically illustrated in real-time on a large focal screen. As people could inspect a visualization of the others’ feelings, the social aspect of the listening experience was reinforced. The emphasis on soundscape listening as a mediator for social exchange was equally important in “Hurly-Burly” [5]. This framework invited users to share their own audio recordings and other material in a social media environment to engage in a social interaction via personalized “friendship compositions”.

Another important category of device-enabled soundscaping is found in the concert context, where audience participatory music-making is a rapidly growing field, spawning more or less persistent mobile phone orchestras [34]. Suggestions for developing a taxonomy of design principles relevant to such works are found in [26].

The works briefly reviewed so far are essentially musical. They show an emphasis on social listening, and sometimes, but not always, have a focal creative person such as a conductor or performer. A different approach to soundscape design is enabled by sonification techniques, in particular when sound spatialization is used.

1.2. Immersive multichannel sonification

Sound spatialization is a particularly useful sonification strategy when the source data describe a physically distributed phenomenon. In a review [8] of almost 500 projects, it was reported that while stereo panning is common, multichannel panning was only used in a sixth of the cases. An even smaller portion employed high-precision methods, such as vector-based amplitude panning (VBAP), HRTF, or Ambisonics (see [25] for an overview of these techniques). The review authors reported that sonification designers often



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explicitly identified sound spatialization as a “natural way” to render source kinematics salient, i.e. location and motion in the phenomenon which were represented by the data. Examples of this approach applied to earth data are found in [24] and [3]. In the latter, a VBAP method was used to create a multichannel sonification of weather data: specifically, hail storms and statistics of the physical injuries that these caused. Because the sonification used a ‘cube’ loudspeaker setup to create a 3D soundscape, sonic movement was evident and listeners could grasp spatial gestures as representing the movements of actual weather systems. The prevalence of injuries was brought to the listener’s attention by a variation in the modulation index of an FM synthesizer, affecting the perceived brightness of the corresponding sound events.

Examples of applications applied to the study of the human brain are found in [1] and [28]. The latter, “Neurospaces”, gives an interesting recent contribution to the discussion of aesthetic sonification. The authors describe it as a musical composition based on the interaction between five instruments and sonifications of fMRI recordings of brain activity. The instruments were dispersed around the audience to represent separate conical sections of the brain. The authors were attentive to the question of how the inherent spatiality in the data could be convincingly mapped to the performance space and thereby become a means for musical expression.

1.3. A novel approach

Despite the fascinating results from multichannel data sonification and the increasingly prevalent and innovative usage of mobile devices in musical and social installation contexts, there are few examples combining the two approaches. In our literature review, we have not been able to find publications describing such projects. The attempts at doing so in “Locust Wrath #3” might thus be a novelty.

2. THE LOCUST WRATH PROJECT

2.1. Surround sonifications for a multimedia performance

The Locust Wrath project [19] started in mid-2013 when one of us (Lindborg) was commissioned to create parts of the sound design for a multimedia dance performance [14]. The concept of aesthetic sonification was important to our initial approach to the material. It is discussed in [17] and will not be further pursued here. The performance was developed in rehearsals with the dancers through a process of guided, collective improvisation. It became clear that the sound design needed to have specific musical characteristics, and a sequence of movements was eventually defined. To flexibly work within this creative environment, tools for interactive sonification were developed in Max (Cycling ’74).

The overarching themes for Locust Wrath were (and are still) climate change and how people might deal with its effects. To support this inquiry, [15] provided us with data sets representing historical meteorological records and future predictions, respectively. On an artistic level, the use of specific weather data is important to the concept. For the presentation in Athens (see Section 2.2), data pertaining to the Mediterranean were used, while for the presentations in Singapore, data sets covering South-East Asia were used. Of equal importance was to identify specific historic periods for the climate data: past and future.

The geographical grid in the climate data, as well as the performance taking place ‘in the round’, suggested a surround sonification soundscape, something we have explored in earlier work, e.g [20]. A virtual instrumentarium was built in Max, consisting of 18 spatialized ‘harps’ with a total of 352 strings. The superposition of geography, virtual instrument spatialization, and physical performance space was strictly adhered to, and is illustrated in Figure 1.

After testing various basic sonic unit generators, we settled on a modified Karplus-Strong physical model of a resonating string. We described the climate-to-sound mapping as follows in a program note: *“If there was rainfall in one geographical area on a certain day, then one specific string was struck at the corresponding time in the piece. If it happened to be hot that day, the string resonated longer. The higher the atmospheric pressure, the more detuned it was. Humidity was mapped to vibrato depth. The wind speed affected the quality of the plectrum that plucks the string, so that stronger wind gave a sharper tone... Sonification compresses time; weeks of data can pass by every second. The sonified soundscapes represent weather systems pushing through the geography in complex patterns. The climate is rendered as a music, whose form - gesture, timbre, intensity, harmony, spatiality - is determined by the data.”*

In summary, the sonification mapping was:

- Precipitation → Pluck string;
- Geographical grid → Spatialization and Tessitura;
- Pressure → Detuning;
- Temperature → Resonance (feedback amount);
- Humidity → Vibrato depth;
- Wind Speed → Excitation smoothing.

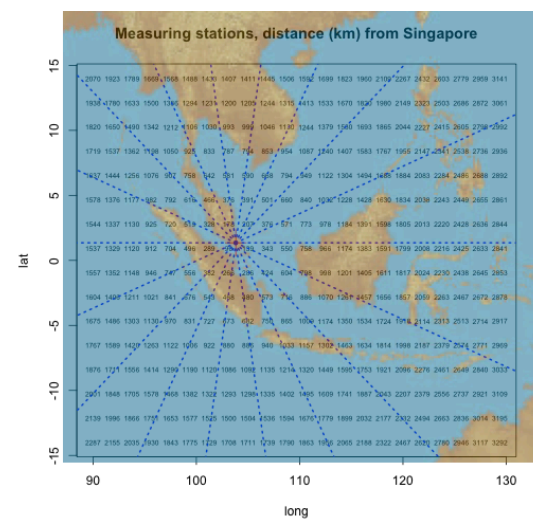


Figure 1. Map of South-East Asia overlaid with 352 geographical gridpoints in 18 sectors, sonified as ‘virtual harps’.

The transfer function in each case was manually adjusted by drawing the shape in the graphic user interface while listening to the results. Once set, the mapping arrangement was not altered. On the other hand, global settings such as data flow rate, fundamental pitch, and mapping limits were designed for each movement separately in order to match the dramatical needs at that point in the performance.

2.2. Locust Wrath in installation and live performance

2.2.1. Installation

The spatialization strategy was entirely reworked for Locust Wrath #2. This was a sound installation in a public space [21] supported by a 7-channel frontal 2D auditory display; see Figure 2. The data represented the predicted weather forty years into the future, i.e. 2015-55. Since the installation took place in Greece, the data was chosen to cover the whole of the Mediterranean Basin with a grid of 300 points. Four 21-channel files were rendered, each 12 minutes in duration and representing one decade of data. They were interspersed with recordings of a child's voice (the composer's daughter) narrating her imagined future while growing older. This 'radio play' artifact was added to the discourse in order to increase accessibility to the piece by lending a human perspective onto the vast temporal developments being sonified. The piece was realized as originally intended, with a custom-built 21-loudspeaker display, in March 2015 in Singapore.



Figure 2. The Locust Wrath #2 installation at the Onassis Cultural Centre in Athens.

2.2.2. Live sonification performance

An adapted version of Locust Wrath #2 was used in a live performance at the *Liquid Architecture Singapore* event in October 2014. As the parameter mapping can be piloted in real-time, the composer 'played' the sonification like an instrument, to a high degree controlling the perceptual effect of the output. While this was an interesting experience, the merits of the attempt were uncertain. The concept of sonification as a systematic and (ideally) objective method clashed with the concept of performance as a (partly) spontaneous interaction. In this performance, the value of one approach undermined the value of the other. The crux of the matter is the opposition between 'ars musica' and 'ars informatica', proposed in [33]; see also [10]. They represent two fundamentally different purposes of making sound: the former as a source for aesthetic experience, the latter as a source for scientific knowledge. As a consequence, they polarize the approaches that sonification designers use, as well as the attitudes that listeners hold. Though the distinction has existed for millennia (see the intriguing description in [8] of data sonification in ancient Mesopotamia; or, consider the Apollonian - Dionysian dielectric), its implications to sonification practices are only recently becoming a theme of interdisciplinary discussion, with input from technical, perceptual, utilitarian, and aesthetic perspectives (cf. [10], especially chapter 7).

Live interactive sonification with Locust Wrath remains a possibility for future work but will not be pursued at this point.



Figure 3. Poster for "Make it New" within which Locust Wrath #3 was a part.

2.3. Immersive soundscapes for multimedia performances

The next step in the project came with the creation of parts of the sound design for two new productions, [12] and [13], on the occasion of ArtsFission's 20th anniversary; see Figure 3. Both were site-specific multimedia dance performances at the National Design Centre in Singapore. This is an open white-box like space with ~300 m² floor area and 3 balcony levels on four sides. Director Angela Liong sought to emphasize an audience participatory and immersive overall character; for example, the dancers and audiences intermingled throughout the space in various configurations.

The physical proximity between performers and visitors suggested that handheld devices might be used as *ad hoc* loudspeakers for an immersive soundscape design. We therefore conceived the idea of an iPhone app [16]. An obvious challenge was the low sound output level from its loudspeaker. The sound of a single device would easily be lost in such a large space. However, we hypothesized, might not the sound of a large number of synchronized devices fuse, and together fill the space? Beyond optimizing the technical audio delivery, it was going to be important to contextualize the user experience of such a soundscape design. Ushers and students helped audience members download and install the app, and made sure they would know how and when to use it in the performance. Its 'solo sequence' in the flow of the performance was quite carefully planned in order to work together with the expected modest sound levels of an iPhone soundscape, so that qualities such as intimacy and immersiveness would be in the foreground.

3. SYSTEM DESIGN IN LOCUST WRATH #3

While Locust Wrath #3 was created for a specific event, we wanted the system to be adaptable to future 'site-generic' events; these might call for other sets of data, mapping strategies, and sound synthesizers. Before going into the details of the iOS implementation, we will relate the visitor experience with the app, and give an overview of the server-client model.

3.1. Visitor perspective

The degree of user interaction in the present system is minimal: the participants are asked to let their devices be roped in as ‘miniature loudspeakers’ and form a distributed auditory display filling the installation space. As seen in Figure 4, the Locust Wrath app is downloaded from iTunes [16]. The audience then logs onto a dedicated wireless local area network, and launches the app.



Figure 4. The Locust Wrath app on iTunes.

Figure 5 shows the user interface after the app has been launched. ‘Test Tone’ buttons are provided so the volume can be adjusted or switched out of silent mode if needed. The participant is prompted to click on the map of the venue to indicate her location within the space. After selection, a red dot appears on the nearest grid point to provide feedback of the selection. Gridpoint IDs are shown for information to indicate that the device is ready for receiving weather data from the server.

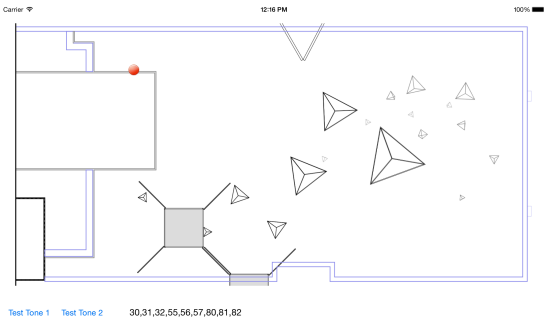


Figure 5. The graphical user interface is a plan of the installation area. The audience member could move about freely during the show, indicating her position (red dot) by clicking on the screen.

3.2. Server – client model

We designed a system based on a server-client model. A central server application, programmed in Max (Cycling 74), runs on a Macintosh desktop computer. As described in Section 2, the application allows interactive, dynamic transformation of raw data to synthesis parameters. Given the physical proportions of the venue, we retrieved climate data in a 25 x 12 grid (thus 300 points) representing a vast geographical area of South-East Asia (cf. Figure 1). Using

the server GUI shown in Figure 6, the sonification mapping was selected as follows:

- Precipitation → Pluck loudness;
- Geographical grid → Spatialization;
- Pressure → Sharpness of attack and Vibrato depth;
- Temperature → Tessitura;
- Humidity → Resonance (feedback amount);
- Wind Speed → Detuning and Vibrato speed,

and as before, the transfer functions were defined heuristically in studio; that is, in a process of subjective improvement of the output, as judged by informal listening and while making gradually smaller and smaller changes to the function parameters. The feed-forward parameter was tested but eventually not used.

The parameters were broadcast over a local area network (LAN) using a high-quality wireless router. The client iOS devices receive all data, but each app only retains data that correspond to its current position in the grid. Audio synthesis is then done locally on each device.

The iOS implementation is currently limited to a Karplus-Strong synthesizer with a polyphony of nine voices. Thus, each device covers a square of nine nodes in the grid. The system requires each device to be assigned a position with respect to its real location in the installation space. There are presently three main location services available to iOS: GPS, cell tower, or iBeacon ([7]). However, since the installation took place indoors and required a high degree of precision, the first two could not be used. A future implementation might investigate the latter system. For the present purpose, we settled on the simple solution of letting the users themselves inform their position via the user interface (see Section 3.1 and Figure 5).

We determined a straightforward internal protocol to pass the synthesis parameters from the server to the clients using tools in [29]. Clients connected to a dedicated WiFi hotspot in a LAN environment. The server broadcasted the entire set of data, i.e. a block of 32 datagram packets each consisting of cell ID (16 bit integer), timestamp (32 bit integer), and synthesizer parameters (7 x 32 bit floats for direct gain, smooth width, frequency, feed-forward gain, feedback gain, LFO depth, and finally LFO speed). See Section 4 for details. The client identified its own cell IDs and selected the appropriate data to play, depending on its assigned location.

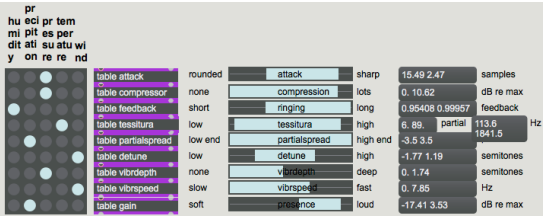


Figure 6. Server GUI for data → sound synthesis mapping and scaling. Transfer functions are set by selecting and dynamically adjusting the parameters of a suitable function, e.g. power, generalized logistic, or trigonometric.

4. iOS IMPLEMENTATION

The system design posed certain challenges for the implementation of the iOS client. Firstly, the iOS devices had to be fast enough to emulate the polyphonic Karplus-Strong synthesizer. The boundary conditions for maximum polyphony, sampling rate and buffering size were investigated. Preventing buffer dropouts and other audible defects was crucial to the overall results.

Secondly, the network conditions inevitably affected the sonic output in terms of audio latency and smoothness of the streaming. To design a system matching the project's need, the network environment, including router and network protocols, was investigated.

Thirdly, since the auditory display was in fact an ad-hoc network consisting of dozens of iOS devices, all the nodes had to work coherently in good synchronization. A mechanism with real-time network capability tolerating the natural instability of the network environment had to 'orchestrate' these devices.

Fourthly, the spatialized assignment proved challenging. We could not utilize a location service such as GPS or cell tower since the project installation happened indoors. It was a challenge to achieve automatic detection of location for each iOS device.

In designing the system, artistic and practical requirements were considered and analyzed. Implementation on multiple platforms was considered and examples in the literature were considered (e.g. [4], [26], [30], [34]). Networked audio programming implies constraints and even mutually exclusive factors, necessitating compromises in order to achieve the overall best outcome. This is crucial especially for the choice of audio buffer size, sampling rate, the number of simultaneous channels, network protocol, and network transfer strategies. In the next section we will discuss these factors.

4.1. Performance limitations

The performance of iOS devices has increased dramatically in recent years. CPU and memory are the most relevant factors determining audio synthesis. We investigated hardware configurations for current devices (from iPhone 4S to 6+) in [9], and found that CPU performance of the more recent devices like iPhone 6 is comparable to a low-end laptop computer such as MacBook Air (2014 early version); they both have a 1.4 GHz Duo Core processor. The RAM memory of an iPhone is smaller than the MacBook's, but that is mainly due to the much simpler user environment of the mobile device where a single application takes over the entire screen at any time. Less user interaction effectively reduces the overall memory requirement on the operating system. However, despite the impressive capacity of recent iOS devices, it remains critical to know their performance boundaries so that the strategy for code implementation is optimal. Moreover, the plethora of iOS versions and hardware setups in circulation makes it difficult to write a single app that will run on all devices.

All iOS audio applications need to use the interfaces provided by the Core Audio API, which is based on cross-platform OpenAL. Core Audio is very effective in dealing with low-latency, real-time audio applications. According to [30], typical iOS audio latency is less than 6 ms, in contrast to Android devices, of which the best device in this review had a latency of 108 ms and others up to three times as long. As a rule of thumb, latency beyond 25 ms is not suitable for

audio applications, since this is the upper limit of what musicians find acceptable in timing-critical tasks such as note onsets in playing rhythmic music. This was one reason for limiting the present implementation to iOS, even though we were aware that the average latency in the network was likely to be significantly larger than the audio latency in the client.

4.2. Audio synthesis

iOS Core audio [6] provides a complete set of mechanisms for audio signal processing. In the Locust Wrath app, we mainly used the Remote I/O object to generate sound. The design goal was to build a robust, fast, responsive, and maintainable app with real-time support. It needed to have the following characteristics: encapsulation of components into abstraction layers; plugin-like mechanism enabling extension to other synthesis methods; and clear hierarchy, i.e. so that low level Core audio API calls are hidden from the higher layers. Moreover, these characteristics will enable porting to other audio platforms in the future.

With these goals in mind, we designed five layers for the Locust Wrath app. The layers are well separated, and communicate with each other via interface classes.

4.3. App layers

At the lowest level there is an audio engine IO layer that handles all the functionalities regarding the Core audio APIs, such as setting up the audio parameters (sampling rate, bit width, buffer size, etc), and enabling the Remote I/O object for real-time audio processing. The latter invokes a handler call-back in which the audio content (in Pulse Code Modulation format) gets filled into the buffer, and is subsequently sent out to the hardware for playback.

After that, there is a channel layer where audio signals can be applied with DSP effects, categorized by the channel number. This layer is also responsible for mixing different sounds into the final output.

The third layer is an audio generator layer containing the synthesizers. Each generator is assigned a channel number to be mixed into the final output. The impulse generator of the Karplus-Strong synthesizer was written as an audio generator in this layer, and can be inserted into the system during run-time. It consists of a comb filter fed by a ramped signal impulse. Six parameters can be updated in real-time: delay, direct gain, feed-forward gain, feedback gain, and LFO (i.e. vibrato) speed and depth. Note that the filter delay affects the pitch of the output. The synthesizer is written as an audio generator in the third layer, and can be inserted into the system in run-time. Also, multiple instances can be created to generate independent string plucks, each with their own channel ID. During the actual playing of the sound installation, weather data is retrieved, filtered, transformed, and scaled in the Max server, and the resulting set of parameters is transferred to the client over the network. The synth picks the parameters up and generates sound accordingly.

A timeline event layer follows, where the event of the notes are arranged in time and triggered at the corresponding timestamp together with the synthesis parameters.

Fifth and last, there is a network layer where the corresponding network data are received and transferred into the playing timeline. This layer is also responsible for handling timestamp data with which all the present devices are synchronized, as well as handling transport control data such as play and stop.

4.4. Network

Issues about network performance were highly critical as the Locust Wrath system relies on real-time streaming of synchronized synthesis parameters. The difficult part is to simultaneously distribute location-tagged data to multiple iOS devices, while maintaining strict timing constraints and overcoming the natural instability of the network. The system was designed to robustly deal with stream interruption and to allow swift recovery of a client after accidental disconnection.

4.4.1. Protocol

An overview with test results of throughput for various protocols in situations with strong timing requests was presented in [27]. The TCP protocol is inherently more stable than UDP; however, its latency and protocol overhead are much larger. A study [11] of TCP performance over 4G networks showed that performance might be significantly increased within the confines of the protocol, but a practical implementation of their method is not yet easily available.

From a practical point of view, in our present case, we gathered that the occasional loss of packets should not cause large problems at a perceptual level. What is more, it does not make sense to retransmit the dropped packets if the actual play position has already passed its timestamp. On the other hand, transport control data, such as play and stop, seemed important to make sure they reach the destination devices. We tested a system with UDP for synthesis parameter data and TCP for control data, but found that UDP was sufficient for control data as well.

Three matters were considered. First, noting that the UDP protocol supports broadcasting, whereas TCP does not, it would save a lot of bandwidth by broadcasting to all devices rather than establish a connection for each device. Second, we were able to use a high quality router (Netgear NighthawkX4 AC2350) to set up an internal WiFi LAN, thus considerably reducing the number of dropped packets, e.g. compared to sending data packages via the Internet. Informal testing of UDP performance recorded ping latencies in the range 1...100 ms, with 90% of the packets arriving within 30 ms; this was considered acceptable for the present application. Third, using UDP simplifies logic on the Max server side, i.e. not having to keep track of TCP connection states.

4.4.2. Stability

The range of the Netgear router's WiFi signal was found to be very satisfactory, with no connection interruptions even with devices separated by ~40 meters in the installation space, or ~30 meters with some obstructions such as plaster or light concrete partitions.

4.4.3. Synchronization

The next problem was to synchronize all iOS device. In order to have a unified timeline for all devices, the timestamp for the current playhead of the server was sent separately. We defined a time synchronization message in the communication protocol to perform this task. However, the frequency of the timestamp messages demanded a consideration of the constraints. The iOS client needs to receive the timestamp sync message frequently enough so

that, in case of a network disconnection, the device can recover 'soon enough' to the proper timestamp. However, receiving the message too frequently will make the timestamp for each device inconsistent due to the fluctuating latencies introduced by the network itself. With these considerations in mind, the synchronization frequency was chosen heuristically, and fine-tuned through testing within the real network environment.

4.4.4. Buffering and recovery

In the present system, prior to play, it is demanded to broadcast the next block, consisting of 32 time-stamped sets of data (see Section 3.2). When the data start to play, the next block is transferred to the buffer. This strategy worked well in the real environment, and the streaming was never interrupted during tests.

4.4.5. Recovery

When a client was accidentally disconnected from the network, the user could simply restart the application. Upon initialization, the client detects that the server is already running, and picks up from the nearest timestamp synchronization message. It starts synthesizing sound as soon as the next block of data is properly buffered, typically within a couple of seconds.

5. CONCLUSION

This paper has outlined the background to the artistic project as a whole and described the system design of Locust Wrath #3 in some detail. The server-client system was employed in four presentations of two multimedia performances ([12], [13]) and showed excellent stability in this demanding setting. Moreover, it was passively accessible for installation visitors during five days of "open house" at the National Design Centre, mainly for demonstration purposes.

We had initially estimated that 30 iOS devices would be sufficient to create a sonification soundscape filling the space under performance conditions, with a crowd of 100+ audience members and performers. At the second showing of "Future Feed", there were approximately 40 devices active simultaneously. The resulting immersive soundscape was perceived as pleasant, intriguing, and overall suitable for the dramatic requests of its 'solo movement' in this performance. However, the low sound levels were noted as problematic. This was compounded by the tendency of audience members to cluster towards the areas where dancers were mainly active. For an optimal experience of the present system, we now estimate that at least twice as many devices are needed. Furthermore, they must be fairly evenly spread out in the space, in order for this system to be effective in constituting an auditory display. Given the broadcasting model, it should be unproblematic to scale up the number of users, perhaps even towards 300, at which point the grid system in the original data might have to be revised.

Some visitors suggested various ways to increase the interactive capacities of the app. These ideas will be followed up in future work. A step in this direction is to introduce some form of audience feedback and/or selection, along the lines of [23] and [35]. This might lead to a form of 'weak' live interactive performance, balancing the opposing aesthetics of 'ars musica' and 'ars informatica', as discussed in Section 2.2.2. However, implementing a two-way TCP

network communication will put additional demands on the network that may limit scalability.

At present, we are working to extend the Locust Wrath app with a concurrent visualization, displayed on the iPhone screen. We believe that this might be effective in a black-box performance space, where audience members can grasp the totality of a distributed audiovisual display from multiple, individual viewpoints. The color association method is based on a CIE Lab color space model that is being investigated in a separate project on crossmodal perception [18].

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